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STD. XI Sci.

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PHYSICS

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  - The Video/pdf links boosting conceptual retention
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PREFACE

"Everything should be made as simple as possible, but not simpler." - *Albert Einstein.*

Having this vision in mind we have created **"Perfect Physics: Std. XI"** as per the latest textbook of Maharashtra State board. It focuses on not just preparing students from examination point of view but also equipping them to understand and appreciate the beauty of the concepts in Physics.

Every chapter in this book begins with a brief introduction of the chapter. Following with:

- **Insights…** provided at the start captivate readers with intriguing revelations and thought-provoking observations, setting the stage for an engaging exploration of each new chapter.
- The chapter is **segregated topic-wise** and encompasses all textual content in the format of Question-Answers. *Textual Exercise questions, Intext questions, 'Can you tell', 'Can you recall', 'Try this'* and *'Activity'* are placed aptly amongst various additional questions in accordance with the flow of subtopic.
- **Numerical Zone** covers numericals along with their step-wise solutions using log calculation (wherever necessary) are covered at the end of each topic followed by **Practice Numericals** (Solutions to which ate provided through QR code) which strengthens the numerical aspect of the students.
- **Important Formulae** are placed after covering last subtopic of the chapter.
- **Exercise** helps the students to gain insight on the various levels of theory and numerical-based questions.
- **Multiple Choice Questions** and **Topic Test** (as per latest paper pattern) assess the students on their range of preparation and the amount of knowledge of each topic.
- **Memory Map** offers easy-to-follow guides that make revising both fun and effective.
- The flow chart on the adjacent page will walk you through the **key features** of the book and elucidate how they have been carefully designed to maximize the student learning.

Perfect Physics, Std. XI Sci. adheres to our vision and achieves several goals: building concepts, developing competence to solve numericals, recapitulation, self-study, self-assessment and student engagement - all while encouraging students toward cognitive thinking.

We hope the book benefits the learner as we have envisioned.

Publisher

Edition: Fifth

The journey to create a complete book is strewn with triumphs, failures and near misses. If you think we've nearly missed something or want to applaud us for our triumphs, we'd love to hear from you.
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KEY FEATURES

Insights...

'Insights...' *starts each chapter with engaging information and curious facts, sparking your interest right from the beginning*

For your knowledge

For Your Knowledge presents fascinating information about the concept covered.

Competitive Corner

Competitive Corner includes selective questions from prominent [NEET (UG), JEE (Main), MHT CET] competitive exams based entirely on the syllabus covered in the chapter.

NCERT Corner

NCERT Corner covers information from NCERT textbook relevant to topic.

Connection

Connections enable students to interlink concepts covered in different chapters.

Brain Teasers

Brain Teasers include challenging questions.

Continued…

KEY FEATURES

Smart Keys

'Smart Keys' comprise a set of remarkable study techniques contrived to benefit students.

Reading between the lines

Reading between the lines provides elaboration or missing fragments of concept which is essential for complete understanding of the concept.

Smart check

Smart Check is a technique to verify the answers. This is our attempt to crosscheck the accuracy of the answer.

Caution

Caution helps students to be watchful against commonly made mistakes.

Strategy

Strategy provides a step-by-step process to break a complex numerical problem into simpler parts.

QR Codes

QR codes provide:

i. Access to a video/PDF in order to boost understanding of a concept or activity

ii. Solutions to:
Practice Numericals,
Additional Numericals for Practice,
Competitive corner, Topic test

Important Formulae

Important Formulae includes all of the key formulae in the chapter.

Memory Map

Memory maps offer easy-to-follow guides that make revising both fun and effective.

CONTENTS

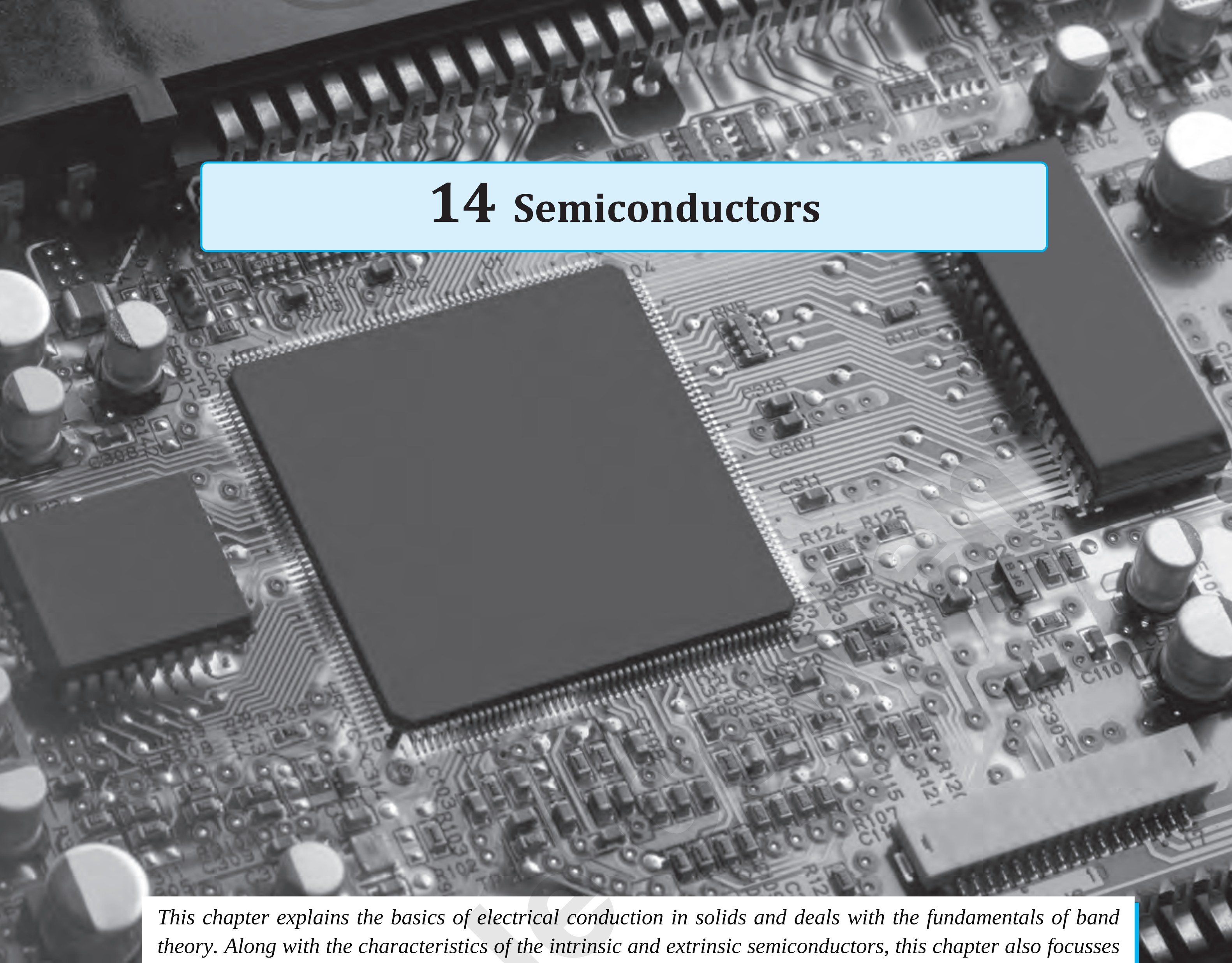
[Reference: Maharashtra State Board of Secondary and Higher Secondary Education, Pune - 04**]**

Note: 1. * mark represents Textual question.

2. # mark represents Intext question.

3. + mark represents Textual examples.

4. symbol represents textual questions that need external reference for an answer.



14 Semiconductors

This chapter explains the basics of electrical conduction in solids and deals with the fundamentals of band theory. Along with the characteristics of the intrinsic and extrinsic semiconductors, this chapter also focusses on explaining the practical applications of diodes made, using these semiconducting materials.
The chapter is allotted weightage of ***5 marks*** *with option and* ***4 marks*** *without option.*

Contents and Concepts

Insights...

1. The first general purpose computer (ENIAC) weighed 30 tonnes and covered an area of 1800 square feet. Whereas, today's smart phones are small enough to fit into a pocket and carry much more memory compared to ENIAC.

Questions and Answers

14.1 Introduction

Semiconductors are materials whose electrical properties can be tailored to suit our requirements. Electrical conductivity of semiconductors lies in between that of good conductors and insulators.
For example:

Conductor	Semiconductor	Insulator
Silver	Silicon	Glass
6.30×10^{7} S m^{-1}	1.56×10^{-3} S m^{-1}	10^{-11} S m^{-1}

14.2 Electrical conduction in solids

Q.1. What are the factors on which electrical conductivity of any solid depends? [2 Marks]

Ans: Electrical conduction in a solid depends on:
i. its temperature
ii. the number of charge carriers
iii. how easily these carries can move inside a solid (mobility)
iv. its crystal structure
v. types and the nature of defects present in a solid.

Q.2. Why are metals good conductor of electricity? [1 Mark]

Ans: Metals are good conductors of electricity due to the large number of free electrons ($\approx 10^{28}$ per m^3) present in them.

Q.3. Give the formula for electrical conductivity of a solid and give significance of the terms involved. [1 Mark]

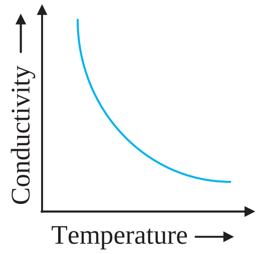
Ans: Electrical conductivity (σ) of a solid is given by
$\sigma = nq\mu$, where,
n = charge carrier density
(number of charge carriers per unit volume)
q = charge on the carriers
μ = mobility of carriers

FOR YOUR KNOWLEDGE

Mobility of a charge carrier is the measure of the ease with which a carrier can move in a material under the action of an external electric field. It depends upon many factors such as mass of the carrier, whether the material is crystalline or amorphous, the presence of structural defects in a material, the nature of impurities in a material and so on.

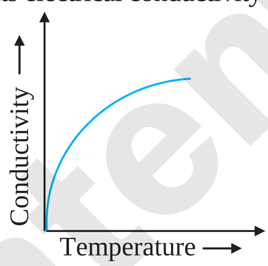
Q.4. Explain in brief temperature dependence of electrical conductivity of metals and semiconductors with the help of graph. [2 Marks]

Ans:
i. The electrical conductivity of a metal decreases with increase in its temperature.



Metal

ii. When the temperature of a semiconductor is increased, its electrical conductivity also increases.



Semiconductor

Q.5. Mention the broad classification of semiconductors along with examples. [1 Mark]

Ans: A broad classification of semiconductors can be:
i. **Elemental semiconductors:** Silicon, germanium
ii. **Compound Semiconductors:** Cadmium sulphide, zinc sulphide, etc.
iii. **Organic Semiconductors:** Anthracene, doped pthalocyanines, polyaniline etc.

FOR YOUR KNOWLEDGE

Elemental semiconductors and compound semiconductors are widely used in electronic industry. However, discovery of organic semiconductors is relatively new and hence they have comparatively lesser applications.

Q.6. What are some electrical properties of semiconductors? [2 Marks]

Ans:
i. Electrical properties of semiconductors are different from metals and insulators due to their unique conduction mechanism.
ii. The electronic configuration of the elemental semiconductors plays a very important role in their electrical properties.
iii. They are from the fourth group of elements in the periodic table.
iv. They have a valence of four.
v. Their atoms are bonded by covalent bonds. At absolute zero temperature, all the covalent bonds are completely satisfied in a single crystal of pure semiconductor like silicon or germanium.

14.3 Band Theory of Solids, a Brief Introduction

Q.7. Explain in detail the distribution of electron energy levels in an isolated atom with the help of an example. **[3 Marks]**

Ans:

i. An isolated atom has its nucleus at the centre which is surrounded by a number of revolving electrons. These electrons are arranged in different and discrete energy levels.

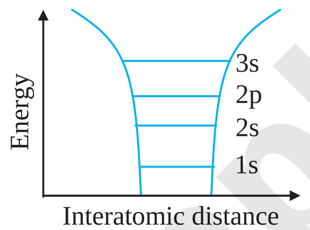
ii. Consider the electronic configuration of sodium (atomic number 11) i.e, $1s^2$, $2s^2$, $2p^6$, $3s^1$. The outermost level 3s can take one more electron but it is half filled in sodium.

iii. The energy levels in each atom are filled according to Pauli's exclusion principle which states that no two similar spin electrons can occupy the same energy level.

iv. That means any energy level can accommodate only two electrons (one with spin up state and the other with spin down state)

v. Thus, there can be two states per energy level.

vi. Figure given below shows the allowed energy levels of a sodium atom by horizontal lines. The curved lines represent the potential energy of an electron near the nucleus due to Coulomb interaction.



Potential energy diagram, energy levels and bands for single atom

Q.8. Explain formation of energy bands in solid sodium with neat labelled energy band diagrams. **[4 Marks]**

Ans:

i. For an isolated sodium atom (atomic number 11) the electronic configuration is given as $1s^2$, $2s^2$, $2p^6$, $3s^1$. The outermost level 3s is half filled in sodium.

ii. The energy levels are filled according to Pauli's exclusion principle.

iii. Consider two sodium atoms close enough so that outer 3s electrons can be considered equally to be part of any atom.

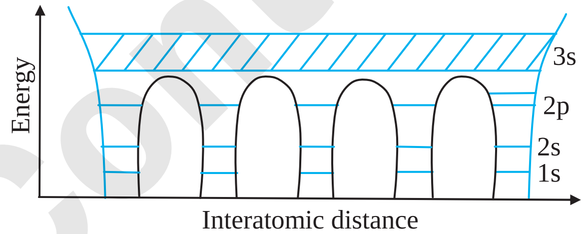
iv. The 3s electrons from both the sodium atoms need to be accommodated in the same level.

v. This is made possible by splitting the 3s level into two sub-levels so that the Pauli's exclusion principle is not violated.

vi. When solid sodium is formed, the atoms come close to each other such that distance between them remains of the order of 2 – 3 Å. Therefore, the electrons from different atoms interact with each other and also with the neighbouring atomic cores.

vii. The interaction between the outer most electrons is more due to overlap while the inner most electrons remain mostly unaffected. Each of these energy levels is split into a large number of sub levels, of the order of Avogadro's number due to number of atoms in solid sodium is of the order of this number.

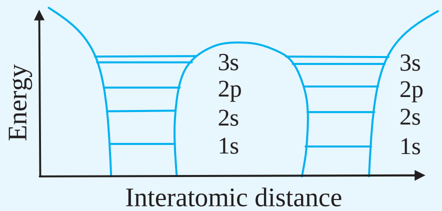
viii. The separation between the sublevels is so small that the energy levels appear almost continuous. This continuum of energy levels is called an energy band. The bands are called 1s band, 2s band, 2p band and so on. Figure below shows these bands in sodium metal.



Band diagram for sodium metal

Reading Between the Lines

Figure given below shows the splitting of the 3s level into two sub levels.



Band diagram for Two atoms

Q.9. Explain concept of valence band and conduction band in solid crystal. **[3 Marks]**

Ans:

i. Valence band (V.B):

a. *The topmost occupied energy level in an atom is the valence level. The energy band formed by valence energy levels of atoms in a solid is called the valence band.*

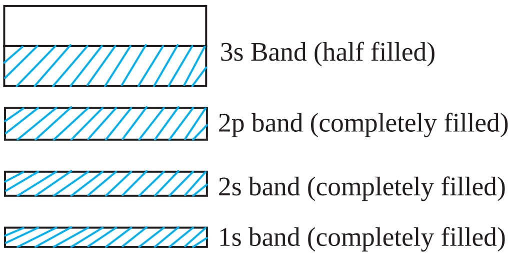
b. In metallic conductors, the valence electrons are loosely attached to the nucleus. At ordinary room temperature, some valence electrons become free. They do not leave the metal surface but can move from atom to atom randomly.

c. Such free electrons are responsible for electric current through conductors.

ii. **Conduction band (C.B):**
  a. *The immediately next energy level that electrons from valence band can occupy is called conduction level. The band formed by conduction levels is called conduction band.*
  b. It is the next permitted energy band beyond valence band.
  c. In conduction band, electrons move freely and conduct electric current through the solids.
  d. An insulator has empty conduction band.

Q.10. Draw neat labelled diagram showing energy bands in sodium. Why broadening of higher bands is different than that of the lower energy bands? [2 Marks]

Ans:



Energy bands in sodium

Broadening of valence and higher bands is more since interaction of these electrons is stronger than the inner most electrons.

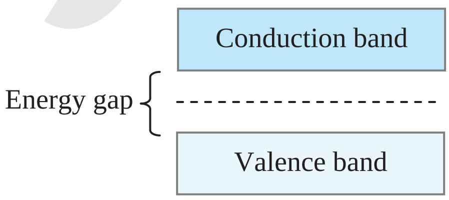
***Q.11. Explain how solids are classified on the basis of band theory of solids. [3 Marks]**

Ans:

i. The solids can be classified into conductors, insulators and semiconductors depending on the distribution of electron energies in each atom.

ii. As an outcome of the small distances between atoms, the resulting interaction amongst electrons and the Pauli's exclusion principle, energy bands are formed in the solids.

iii. In metals, conduction band and valence band overlap. However, in a semiconductor or an insulator, there is gap between the bottom of the conduction band and the top of the valence band. This is called the energy gap or the band gap.



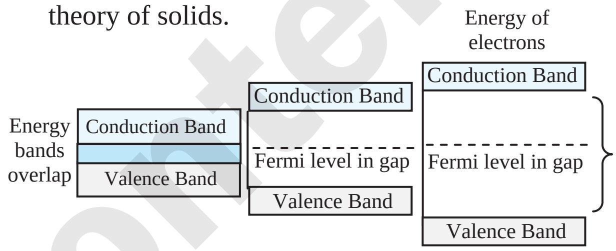
(a) Energy bands for a typical solid

iv. For metals, the valence band and the conduction band overlap and there is no band gap as shown in figure (b). Therefore, electrons can easily gain electrical energy when an external electric field is applied and are easily available for conduction.

v. In case of semiconductors, the band gap is fairly small, of the order of 1 eV or less as shown in figure (c). Hence, with application of external electric field, electrons get excited and occupy energy levels in conduction band. These can take part in conduction easily.

vi. Insulators, on the contrary, have a wide gap between valence band and conduction band of the order of 5 eV (for diamond) as shown in figure (d). Therefore, electrons find it very difficult to gain sufficient energy to occupy energy levels in conduction band.

vii. Thus, an energy band gap plays an important role in classifying solids into conductors, insulators and semiconductors based on band theory of solids.



(b) Metal (c) Semiconductor (d) Insulator

Band Structure

FOR YOUR KNOWLEDGE

The highest energy level in the conduction band occupied by electrons in a crystal at absolute zero temperature is called Fermi level. The energy corresponding to this level is called Fermi energy.

Q.12. State the conditions when electrons of a semiconductor can take part in conduction. [2 Marks]

Ans:

i. All the energy levels in a band, including the topmost band, in a semiconductor are completely occupied at absolute zero.

ii. At some finite temperature T, few electrons gain thermal energy of the order of kT, where k is the Boltzmann constant.

iii. Electrons in the bands between the valence band cannot move to higher band since these are already occupied.

iv. Only electrons from the valence band can be excited to the empty conduction band, if the thermal energy gained by these electrons is greater than the band gap.

v. Electrons can also gain energy when an external electric field is applied to a solid. Energy gained due to electric field is smaller, hence only electrons at the topmost energy level gain such energy and participate in electrical conduction.

Q.13. Define 1 eV. **[1 Mark]**

Ans: *1 eV is the energy gained by an electron while it overcomes a potential difference of one volt. 1 eV = 1.6 × 10^{-19} J.*

Q.14. C, Si and Ge have same lattice structure. Why is C insulator while Si and Ge intrinsic semiconductors? **[2 Marks] (NCERT)**

Ans:

i. The 4 valence electrons of C, Si or Ge lie respectively in the second, third and fourth orbit.

ii. Energy required to take out an electron from these atoms (i.e., ionisation energy E_g) will be least for Ge, followed by Si and highest for C.

iii. Hence, number of free electrons for conduction in Ge and Si are significant but negligibly small for C, so C is insulator.

***Q.15. What is the importance of energy gap in a semiconductor?** **[2 Marks]**

Ans:

i. *The gap between the bottom of the conduction band and the top of the valence band is called the energy gap or the band gap.*

ii. This band gap is present only in semiconductors and insulators.

iii. Magnitude of the band gap plays a very important role in the electronic properties of a solid.

iv. Band gap in semiconductors is of the order of 1 eV.

v. If electrons in valence band of a semiconductor are provided with energy more than band gap energy (in the form of thermal energy or electrical energy), then the electrons get excited and occupy energy levels in conduction band. These electrons can easily take part in conduction.

14.4 Intrinsic Semiconductor

Q.16. What is intrinsic semiconductor? **[1 Mark]**

Ans: *A pure semiconductor is known as intrinsic semiconductor.*

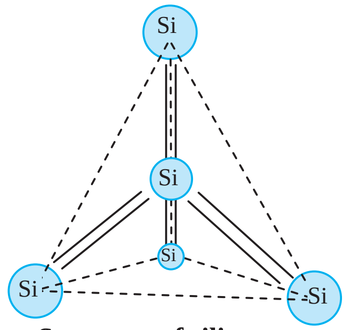
Q.17. Explain characteristics and structure of silicon using a neat labelled diagram. **[2 Marks]**

Ans:

i. Silicon (Si) has atomic number 14 and its electronic configuration is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$.

ii. Its valence is 4.

iii. Each atom of Si forms four covalent bonds with its neighbouring atoms. One Si atom is surrounded by four Si atoms at the corners of a regular tetrahedron as shown in the figure.



Structure of silicon

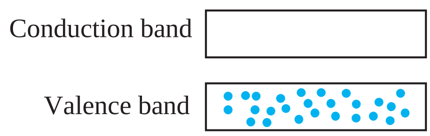
Q.18. Describe in detail formation of holes in intrinsic semiconductor. **[3 Marks]**

Ans:

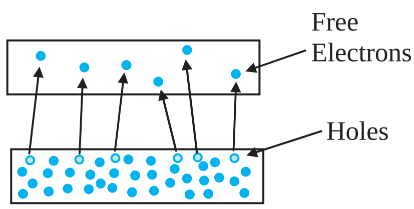
i. In intrinsic semiconductor at absolute zero temperature, all valence electrons are tightly bound to respective atoms and the covalent bonds are complete.

ii. Electrons are not available to conduct electricity through the crystal because they cannot gain enough energy to get into higher energy levels [Figure (a)].

iii. At room temperature, however, a few covalent bonds are broken due to heat energy produced by random motion of atoms. Some of the valence electrons can be moved to the conduction band. This creates a vacancy in the valence band as shown in figure (b).



(a) At absolute zero



(b) At room temperature

iv. These vacancies of electrons in the valence band are called holes. The holes are thus absence of electrons in the valence band and they carry an effective positive charge.

CONNECTIONS

For points (i) and (ii)

In Chapter 7, you have studied in detail about absolute zero temperature and how motion of particles gets ceased at this temperature.

*Q.19. **On which factors does the electrical conductivity of a pure semiconductor depend at a given temperature?** [1 Mark]

Ans: For pure semiconductor, the number density of free electrons and number density of holes is equal. Thus, at a given temperature, the conductivity of pure semiconductor depends on the number density of charge carriers in the semiconductor.

Q.20. How does electric conduction take place inside pure silicon? [3 Marks]

Ans:

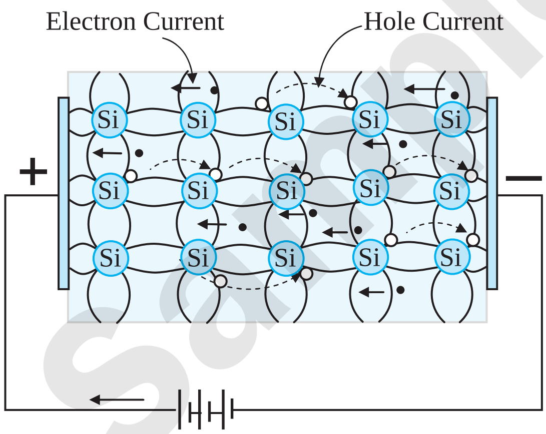
i. There are two different types of charge carriers in a pure semiconductor. One is the electron and the other is the hole or absence of electron.

ii. Electrical conduction takes place by transportation of both carriers or any one of the two carriers in a semiconductor.

iii. When a semiconductor is connected in a circuit, electrons, being negatively charged, move towards positive terminal of the battery.

iv. Holes have an effective positive charge, and move towards negative terminal of the battery. Thus, the current through a semiconductor is carried by two types of charge carriers moving in opposite directions.

v. Given figure represents the current through pure silicon.



Q.21. Why do holes not exist in conductor? [2 Marks]

Ans:

i. In case of semiconductors, there is one missing electron from one of the covalent bonds.

ii. The absence of electron leaves an empty space called as hole; each hole carries an effective positive charge.

iii. In case of an conductor, number of free electrons are always available for conduction. There is no absence of electron in it. Hence holes do not exist in conductor.

14.5 Extrinsic Semiconductor

Q.22. What is the need for doping an intrinsic semiconductor? [2 Marks]

Ans: The electric conductivity of an intrinsic semiconductor is very low at room temperature; hence no electronic devices can be fabricated using them. Addition of a small amount of a suitable impurity to an intrinsic semiconductor increases its conductivity appreciably. Hence, intrinsic semiconductors are doped with impurities.

Q.23. Explain what is doping. [2 Marks]

Ans:

i. *The process of adding impurities to an intrinsic semiconductor is called doping.*

ii. The impurity atoms are called dopants which may be either trivalent or pentavalent. The parent atoms are called hosts.

iii. The dopant material is so selected that it does not disturb the crystal structure of the host.

iv. The size and the electronic configuration of the dopant should be compatible with that of the host.

v. Doping is expressed in ppm (parts per million). i.e., one impurity atom per one million atoms of the host.

vi. Doping significantly increases the concentration of charge carriers.

Q.24. What is an extrinsic semiconductor? [1 Mark]

Ans: *The semiconductor with impurity is called a doped semiconductor or an extrinsic semiconductor.*

*Q.25. **Which element would you use as an impurity to make germanium an n-type semiconductor?** [1 Mark]

Ans: Germanium can be made an n-type semiconductor by doping it with pentavalent impurity, like phosphorus (P), arsenic (As) or antimony (Sb).

Q.26. Draw neat diagrams showing schematic electronic structure of:

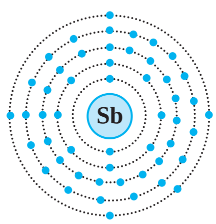
i. A pentavalent atom [Antimony (Sb)]

ii. A trivalent atom [Boron (B)]

[1 Mark Each]

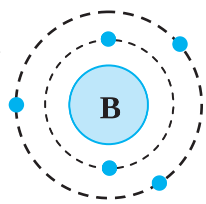
Ans:

i.



Schematic electronic structure of antimony

ii.



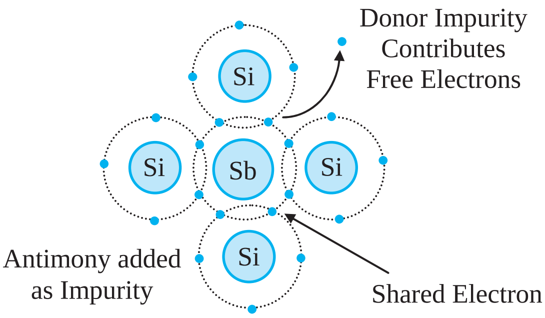
Schematic electronic structure of boron.

Q.27. With the help of neat diagram, explain the structure of n-type semiconductor in detail. **[3 Marks]**

Ans:

i. When silicon or germanium crystal is doped with a pentavalent impurity such as phosphorus, arsenic, or antimony we get n-type semiconductor.

ii. When a dopant atom of 5 valence electrons occupies the position of a Si atom in the crystal lattice, 4 electrons from the dopant form bonds with 4 neighbouring Si atoms and the fifth electron from the dopant remains very weakly bound to its parent atom.



Pentavalent impurity in silicon crystal

iii. To make this electron free even at room temperature, very small energy is required. It is 0.01 eV for Ge and 0.05 eV for Si.

iv. As this semiconductor has large number of electrons in conduction band and its conductivity is due to negatively charged carriers, it is called n-type semiconductor.

v. The n-type semiconductor also has a few electrons and holes produced due to the thermally broken bonds.

vi. The density of conduction electrons (n_e) in a doped semiconductor is the sum total of the electrons contributed by donors and the thermally generated electrons from the host.

vii. The density of holes (n_h) is only due to the thermally generated holes of the host Si atoms.

viii. Thus, the number of free electrons exceeds the number of holes ($n_e >> n_h$). Thus, in n-type semiconductor electrons are the majority carriers and holes are the minority carriers.

Q.28. What are some features of n-type semiconductor? **[2 Marks]**

Ans:

i. These are materials doped with pentavalent impurity (donors) atoms.

ii. Electrical conduction in these materials is due to majority charge carriers i.e., electrons.

iii. The donor atom loses electrons and becomes positively charged ions.

iv. Number of free electrons is very large compared to the number of holes, $n_e >> n_h$. Electrons are majority charge carriers.

v. When energy is supplied externally, negatively charged free electrons (majority charges carries) and positively charged holes (minority charges carries) are available for conduction.

Q.29. With the help of neat diagram, explain the structure of p-type semiconductor in detail. **[3 Marks]**

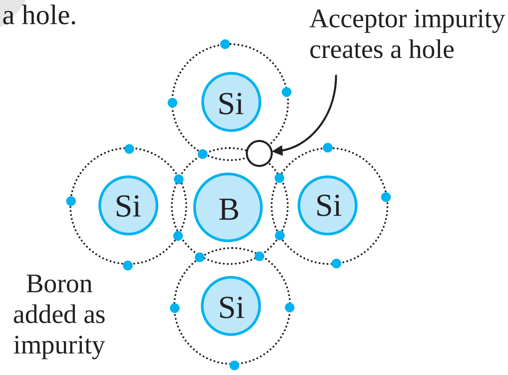
Ans:

i. When silicon or germanium crystal is doped with a trivalent impurity such as boron, aluminium or indium, we get a p-type semiconductor.

ii. The dopant trivalent atom has one valence electron less than that of a silicon atom. Every trivalent dopant atom shares its three electrons with three neighbouring Si atoms to form covalent bonds. But the fourth bond between silicon atom and its neighbour is not complete.

iii. The incomplete bond can be completed by another electron in the neighbourhood from Si atom.

iv. The shared electron creates a vacancy in its place. This vacancy or the absence of electron is a hole.



A trivalent impurity in a silicon crystal

v. Thus, a hole is available for conduction from each acceptor impurity atom.

vi. Holes are majority carriers and electrons are minority carriers in such materials. Acceptor atoms are negatively charged ions and majority carriers are holes. Therefore, extrinsic semiconductor doped with trivalent impurity is called a p-type semiconductor.

vii. For a p-type semiconductor, $n_h >> n_e$.

Q.30. What are some features of p-type semiconductors? **[2 Marks]**

Ans:

i. These are materials doped with trivalent impurity atoms (acceptors).

ii. Electrical conduction in these materials is due to majority charge carriers i.e., holes.

iii. The acceptor atoms acquire electron and become negatively charged-ions.

iv. Number of holes is very large compared to the number of free electrons. $n_h >> n_e$.

v. When energy is supplied externally, positively charged holes (majority charge carriers) and negatively charged free electrons (minority charge carriers) are available for conduction.

Q.31. What are donor and acceptor impurities? **[2 Marks]**

Ans:

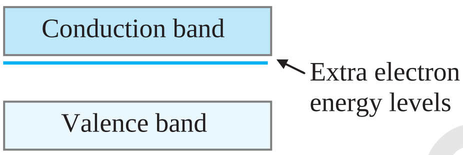
i. Every pentavalent dopant atom which donates one electron for conduction is called a donor impurity.

ii. Each trivalent atom which can accept an electron is called an acceptor impurity.

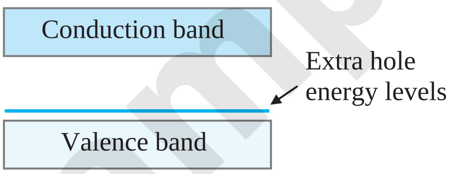
Q.32. Explain the energy levels of both donor and acceptor impurities with a schematic band structure. **[2 Marks]**

Ans:

i. The free electrons donated by the donor impurity atoms occupy energy levels which are in the band gap and are close to the conduction band.



ii. The vacancies of electrons or the extra holes are created in the valence band due to addition of acceptor impurities. The impurity levels are created just above the valence band in the band gap.



Q.33. Distinguish between p-type and n-type semiconductor. **[2 Marks]**

Ans:

No.	p-type semiconductor	n-type semiconductor
i.	The impurity of some trivalent element like B, Al, In, etc. is mixed with semiconductor.	The impurity of some pentavalent element like P, As, Sb, etc. is mixed with semiconductor.
ii.	The impurity atom accepts one electron hence the impurities added are known as acceptor impurities.	The impurity atom donates one electron, hence the impurities added are known as donor impurities.
iii.	The holes are majority charge carriers and electrons are minority charge carriers.	The electrons are majority charge carriers and holes are minority charge carriers.
iv.	The acceptor energy level is close to the valence band and far away from conduction band.	Donor energy level is close to the conduction band and far away from valence band.

Q.34. What is the charge on a p-type and n-type semiconductor? **[1 Mark]**

Ans: n-type as well as p-type semiconductors are electrically neutral.

READING BETWEEN THE LINES

i. *The n-type semiconductor has excess of electrons but these extra electrons are supplied by the donor atoms which become positively charged.*

ii. *Since each atom of donor impurity is electrically neutral, the semiconductor as a whole is electrically neutral.*

iii. *Here, excess electron refers to an excess with reference to the number of electrons needed to complete the covalent bonds in a semiconductor crystal. These extra free electrons increase the conductivity of the semiconductor.*

iv. *Similarly, a p-type semiconductor has holes or absence of electrons in some energy levels.*

v. *When an electron from a host atom fills this level, the host atom is positively charged and the dopant atom is negatively charged but the semiconductor as a whole is electrically neutral.*

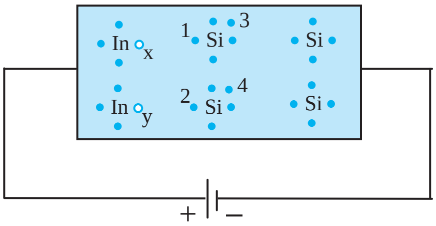
vi. *Thus, n-type as well as p-type semiconductors are electrically neutral.*

Q.35. Explain the transportation of holes inside a p-type semiconductor. **[2 Marks]**

Ans:

i. Consider a p-type semiconductor connected to terminals of a battery as shown.

ii. When the circuit is switched on, electrons at 1 and 2 are attracted to the positive terminal of the battery and occupy nearby holes at x and y. This creates holes at the positions 1 and 2 previously occupied by electrons.



iii. Next, electrons at 3 and 4 move towards the positive terminal and create holes in their previous positions.

iv. But, the holes are captured at the negative terminal by the electrons supplied by the battery.

v. In this way, holes are transported from one place to other and density of holes is kept constant so long as the battery is working.

***Q.36. Why is the conductivity of an n-type semiconductor greater than that of p-type semiconductor even when both of these have same level of doping?** **[2 Marks]**

Ans:

i. In a p-type semiconductor, holes are majority charge carriers.

ii. When a p-type semiconductor is connected to terminals of a battery, holes, which are not actual charges, behave like a positive charge and get attracted towards the negative terminal of the battery.

iii. During transportation of hole, there is an indirect movement of electrons.

iv. The drift speed of these electrons is less than that in the n-type semiconductors. Mobility of the holes is also less than that of the electrons.

v. As, electrical conductivity depends on the mobility of charge carriers, the conductivity of a n-type semiconductor is greater than that of p-type semiconductor even when both of these have same level of doping.

CONNECTIONS

For point (iv)

In Chapter 11, you have studied in detail about drift speed of charge carriers.

***Q.37. Distinguish between intrinsic semiconductors and extrinsic semiconductors.** **[2 Marks]**

Ans:

Sr. No.	Intrinsic semiconductors	Extrinsic semiconductors
i.	A pure semiconductor is known as intrinsic semiconductors.	The semiconductor, resulting from mixing of impurity in it, is known as extrinsic semiconductors.
ii.	Their conductivity is low at room temperature.	Their conductivity is high even at room temperature.
iii.	Its electrical conductivity is a function of temperature alone.	Its electrical conductivity depends upon the temperature as well as on the quantity of impurity atoms doped in the structure.
iv.	The number density of holes (n_h) is same as the number density of free electron (n_e) ($n_h = n_e$).	The number density of free electrons and number density of holes are unequal.

FOR YOUR KNOWLEDGE

i. In an intrinsic semiconductor, number density of charge carriers (n_i) is same as the number density of holes as well as that of electrons. i.e.,

$$n_i = n_e = n_h$$

ii. In an extrinsic semiconductor, number density of holes and electrons is unequal. Here, at thermal equilibrium, the product of free electrons (negative charges) i.e., n_e and free holes (positive charges) i.e., n_h is always constant and that constant quantity is given by,

$$n_e\, n_h = n_i^2$$

This relationship is called mass-action law.

Numerical Zone

+Q.38. A pure Si crystal has 4×10^{28} atoms m^{-3}. It is doped by 1 ppm concentration of antimony. Calculate the number of electrons and holes. Given $n_i = 1.2 \times 10^{16}/m^3$.

(Example 14.1 of Textbook page no. 248)

[2 Marks]

Solution:

As, the atom is doped with 1 ppm concentration of antimony (Sb).

1 ppm = 1 parts per one million atoms. = $1/10^6$

$\therefore$ no. of Sb atoms = $\dfrac{\text{Total no. of Si atoms}}{10^6}$

$$= \frac{4\times10^{28}}{10^6} = 4\times10^{22}\ m^{-3}$$

i.e., total no. of extra free electrons (n_e)

= $\mathbf{4 \times 10^{22}\ m^{-3}}$.

$\because$ $n_i^2 = n_e\, n_h$

$\therefore \quad n_h = \dfrac{n_i^2}{n_e} = \dfrac{(1.2\times10^{16})^2}{4\times10^{22}}$

$= \dfrac{144\times10^{30}}{4\times10^{22}}$

$= 36 \times 10^8 = \mathbf{3.6 \times 10^9\ m^{-3}}$.

Ans: The number of electrons and holes in doped Si atom will be **4×10^{22} m^{-3}** and **3.6×10^9 m^{-3}** respectively.

+**Q.39. A pure silicon crystal at temperature of 300 K has electron and hole concentration 1.5×10^{16} m^{-3} each. ($n_e = n_h$). Doping by indium increases n_h to 4.5×10^{22} m^{-3}. Calculate n_e for the doped silicon crystal.**

(Example 14.2 of Textbook page no. 249)

[2 Marks]

Solution:

Given: At 300 K, $n_i = n_e = n_h = 1.5 \times 10^{16}$ m^{-3}
After doping $n_h = 4.5 \times 10^{22}$ m^{-3}

To find: Number density of electrons (n_e)

Formula: $n_i^2 = n_e\, n_h$

Calculation: From formula,

$n_e = \dfrac{n_i^2}{n_h} = \dfrac{(1.5\times10^{16})^2}{4.5\times10^{22}}$

$= \dfrac{255\times10^{30}}{45\times10^{21}} = \mathbf{5 \times 10^9\ m^{-3}}$.

Ans: The number density of electrons after doping is **5×10^9 m^{-3}**.

Q.40. A semiconductor has equal electron and hole concentration of 2×10^8 m^{-3}. On doping with a certain impurity, the electron concentration increases to 4×10^{10} m^{-3}, then calculate the new hole concentration of the semiconductor.

[2 Marks]

Solution:

Given: $n_i = 2 \times 10^8$ m^{-3}, $n = 4 \times 10^{10}$ m^{-3}
After doping $n_h = 10^{21}$ m^{-3}

To find: Number density of holes (n_h)

Formula: $n_i^2 = n_e n_h$

Calculation: From formula,

$n_h = \dfrac{n_i^2}{n_e} = \dfrac{(2\times10^8)^2}{4\times10^{10}} = \mathbf{10^6\ m^{-3}}$

Ans: The number density of holes after doping is **10^6 m^{-3}**.

Practice Numericals

1. A pure semiconductor contains equal number of electrons and holes. The concentration is 6×10^8/ m^3. On doping it with an impurity its electron concentration increases to 12×10^{12}/ m^3. Calculate the new hole concentration. **[2 Marks]**

Ans: 3×10^4/ m^3

2. A Ge specimen is doped with Al. The concentration of acceptor atoms is ~10^{21} atoms/m^3. Given that the intrinsic concentration of electron-hole pairs is ~10^{19}/m^3, calculate the concentration of electrons in the specimen. **[2 Marks]**

Ans: 10^{17} m^{-3}

14.6 p-n Junction

Q.41. What is a p-n junction? **[1 Mark]**

Ans: *When n-type and p-type semiconductor materials are fused together, the junction formed is called as p-n junction.*

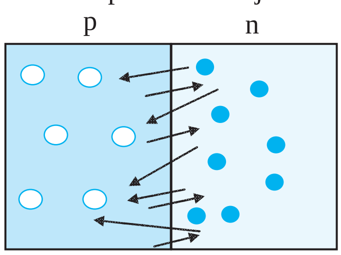
Q.42. Explain the process of diffusion in p-n junction. **[3 Marks]**

Ans:

i. The transfer of electrons and holes across the p-n junction is called diffusion.

ii. When an n-type and a p-type semiconductor materials are fused together, initially, the number of electrons on the n-side of the junction is very large compared to the number of electrons on the p-side. The same is true for the number of holes on the p-side and on the n-side.

iii. Thus, a large difference in density of carriers exists on both sides of the p-n junction. This difference causes migration of electrons from the n-side to the p-side of the junction.



Diffusion of charge carriers across a junction.

iv. They fill up the holes in the p-type material and produce negative ions.

v. When the electrons from the n-side of a junction migrate to the p-side, they leave behind positively charged donor ions on the n-side. Effectively, holes from the p-side migrate into the n-region.

vi. As a result, in the p-type region near the junction there are negatively charged acceptor ions, and in the n-type region near the junction there are positively charged donor ions.

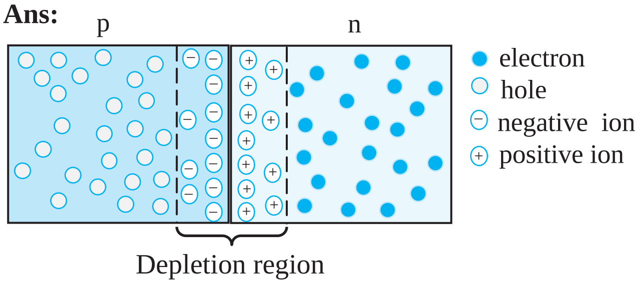
vii. The extent up to which the electrons and the holes can diffuse across the junction depends on the density of the donor and the acceptor ions on the n-side and the p-side respectively, of the junction.

Q.43. Define potential barrier. **[1 Mark]**

Ans: *The diffusion of carriers across the junction and resultant accumulation of positive and negative charges across the junction builds a potential difference across the junction. This potential difference is called the potential barrier.*

Q.44. Draw neat labelled diagrams for potentials barrier and depletion layer in a p-n junction. **[2 Marks]**

Ans:



Potential barrier and the depletion layer

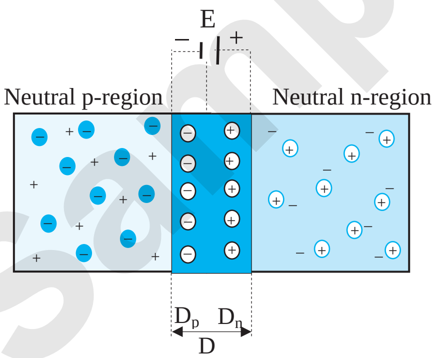
Q.45. Explain in brief electric field across a p-n junction with a neat labelled diagram. **[2 Marks]**

Ans:

i. When p-type semiconductor is fused with n-type semiconductor, a depletion region is developed across the junction.

ii. The n-side near the boundary of a p-n junction becomes positive with respect to the p-side because it has lost electrons and the p-side has lost holes.

iii. Thus, the presence of impurity ions on both sides of the junction establishes an electric field across this region such that the n-side is at a positive voltage relative to the p-side.



Electric field across a junction

***Q.46. Explain the importance of the depletion region in a p-n junction diode.** **[3 Marks]**

Ans:

i. *The region across the p-n junction where there are no charges is called the depletion layer or the depletion region.*

ii. During diffusion of charge carriers across the junction, electrons migrate from the n-side to the p-side of the junction. At the same time, holes are transported from p-side to n-side of the junction.

iii. As a result, in the p-type region near the junction there are negatively charged acceptor ions, and in the n-type region near the junction there are positively charged donor ions.

iv. The potential barrier thus developed, prevents continuous flow of charges across the junction. A state of electrostatic equilibrium is thus reached across the junction.

v. Free charge carriers cannot be present in a region where there is a potential barrier. This creates the depletion region.

vi. In absence of depletion region, all the majority charge carriers from n-region (i.e., electron) will get transferred to the p-region and will get combined with the holes present in that region. This will result in the decreased efficiency of p-n junction.

vii. Hence, formation of depletion layer across the junction is important to limit the number of majority carriers crossing the junction.

Q.47. What is the need of biasing a p-n junction? **[1 Mark]**

Ans:

i. Due to potential barrier across depletion region, charge carriers require extra energy to overcome the barrier.

ii. A suitable voltage needs to be applied to the junction externally, so that these charge carriers can overcome the potential barrier and move across the junction.

Q.48. Explain the mechanism of forward biased p-n junction. **[3 Marks]**

Ans:

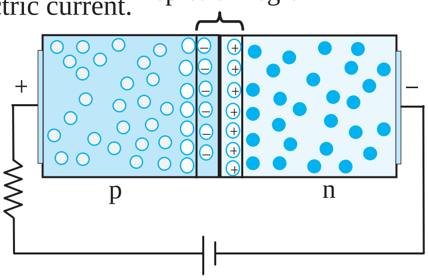
i. In forward bias, a p-n junction is connected in an electric circuit such that the p-region is connected to the positive terminal and the n-region is connected to the negative terminal of an external voltage source.

ii. The external voltage effectively opposes the built-in potential of the junction. The width of potential barrier is thus reduced.

iii. Also, negative charge carriers (electrons) from the n-region are pushed towards the junction.

iv. A similar effect is experienced by positive charge carriers (holes) in the p-region and they are pushed towards the junction.

v. Both the charge carriers thus find it easy to cross over the barrier and contribute towards the electric current.



Forward biased p-n junction

Q.49. Explain the mechanism of reverse biased p-n junction. **[3 Marks]**

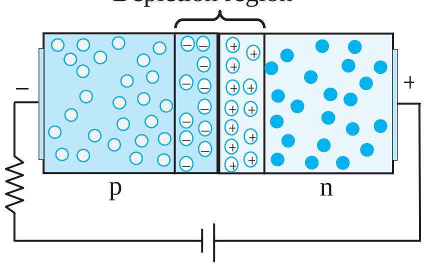
Ans:

i. In reverse biased, the p-region is connected to the negative terminal and the n-region is connected to the positive terminal of the external voltage source. This external voltage effectively adds to the built-in potential of the junction. The width of potential barrier is thus increased.

ii. Also, the negative charge carriers (electrons) from the n-region are pulled away from the junction.

iii. Similar effect is experienced by the positive charge carriers (holes) in the p-region and they are pulled away from the junction.

iv. Both the charge carriers thus find it very difficult to cross over the barrier and thus do not contribute towards the electric current.



Reverse biased p-n junction

*__Q.50. Discuss the effect of external voltage on the width of depletion region of a p-n junction.__ **[2 Marks]**

Ans:

i. A p-n junction can be connected to an external voltage supply in two possible ways.

ii. A p-n junction is said to be connected in a forward bias when the p-region connected to the positive terminal and the n-region is connected to the negative terminal of an external voltage source.

iii. In forward bias connection, the external voltage effectively opposes the built-in potential of the junction. The width of depletion region is thus reduced.

iv. The second possibility of connecting p-n junction is in reverse biased electric circuit.

v. In reverse bias connection, the p-region is connected to the negative terminal and the n-region is connected to the positive terminal of the external voltage source. This external voltage effectively adds to the built-in potential of the junction. The width of potential barrier is thus increased.

Q.51. State some important features of the depletion region. **[2 Marks]**

Ans:

i. It is formed by diffusion of electrons from n-region to the p-region. This leaves positively charged ions in the n-region.

ii. The p-region accumulates electrons (negative charges) and the n-region accumulates the holes (positive charges).

iii. The accumulation of charges on either sides of the junction results in forming a potential barrier and prevents flow of charges across it.

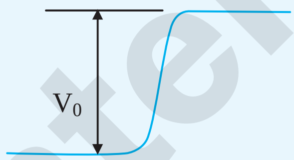
iv. There are no charges in this region.

v. The depletion region has higher potential on the n-side and lower potential on the p-side of the junction.

NCERT CORNER

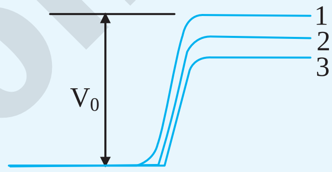
- **Graph showing variation of barrier potential:**

i.



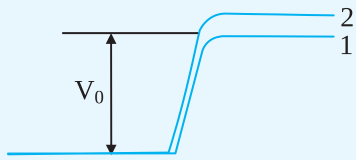
Barrier potential under no bias

ii.



Barrier potential
(1) Without battery
(2) Low voltage battery and
(3) High voltage battery.

iii.

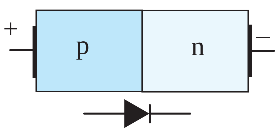


Barrier potential under reverse bias.

14.7 a p-n Junction Diode

Q.52. What is p-n junction diode? Draw its circuit symbol. **[2 Marks]**

Ans: *A p-n junction, when provided with metallic connectors on each side is called a junction diode or simply, a diode.*



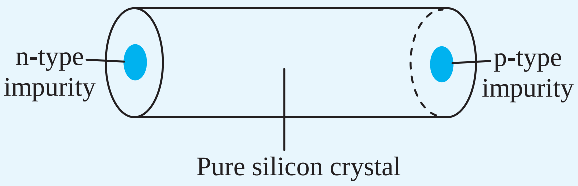
Reading Between the Lines

Diode is a device with two electrodes or di-electrodes.

For Your Knowledge

Do You Know? *(Textbook page no.251)*

Fabrication of p-n junction diode:
In practice, a p-n junction is formed from a crystalline structure of silicon or germanium by adding carefully controlled amounts of donor and acceptor impurities.



The impurities grow on either side of the crystal after heating in a furnace. Electrons and holes combine at the centre and the depletion region develops. A junction is thus formed.
Electrodes are inserted after cutting transverse sections and hundreds of diodes are prepared. All semiconductor devices, including ICs, are fabricated by 'growing' junctions at the required locations.

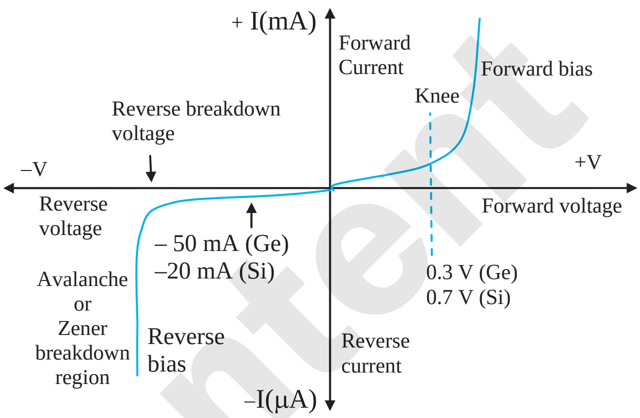
Mobility of a hole is less than that of an electron and the hole current is lesser. This imbalance between the two currents is removed by increasing the doping percentage in the p-region. This ensures that the same current flows through the p-region and the n-region of the junction.

Q.53. Explain asymmetrical flow of current in p-n junction diode in detail. **[3 Marks]**

Ans:

(a) Forward bias (b) Reverse bias

i. The barrier potential is reduced in forward biased mode and it is increased in reverse biased mode.
ii. Carriers find it easy to cross the junction in forward bias and contribute towards current because the barrier width is reduced and they are pushed towards the junction and gain extra energy to cross the junction.
iii. The current through the diode in forward bias is large and of the order of a few milliamperes (10^{-3} A) for a typical diode.
iv. When connected in reverse bias, width of the potential barrier is increased and the carriers are pushed away from the junction so that very few carriers can cross the junction and contribute towards current.
v. This results in a very small current through a reverse biased diode. The current in reverse biased diode is of the order of a few microamperes (10^{-6} A).
vi. When the polarity of bias voltage is reversed, the width of the depletion layer changes. This results in asymmetrical current flow through a diode as shown in figure.

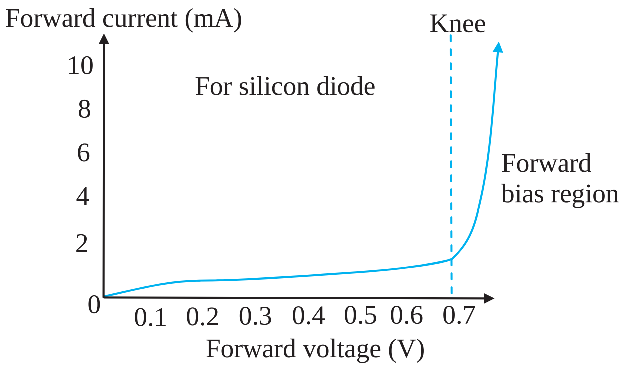


Asymmetrical current flow through a diode.

***Q.54. Explain the I-V characteristic of a forward biased junction diode.** **[3 Marks]**

Ans:

i. Figure given below shows the I-V characteristic of a forward biased diode.



Forward biased characteristic of a diode

ii. When connected in forward bias mode, initially, the current through diode is very low and then there is a sudden rise in the current.
iii. The point at which current rises sharply is shown as the 'knee' point on the I-V characteristic curve.
iv. The corresponding voltage is called the knee voltage. It is about 0.7 V for silicon and 0.3 V for germanium.
v. A diode effectively becomes a short circuit above this knee point and can conduct a very large current.

vi. To limit current flowing through the diode, resistors are used in series with the diode.

vii. If the current through a diode exceeds the specified value, the diode can heat up due to the Joule heating and this may result in its physical damage.

Q.55. What is knee voltage? **[1 Mark]**

Ans: In forward bias mode, the voltage for which the current in a p-n junction diode rises sharply is called knee voltage.

Q.56. What is a forward current in case of zero biased p-n junction diode? **[1 Mark]**

Ans: When the diode terminals are shorted together, some holes (majority carriers) in the p-side have enough thermal energy to overcome the potential barrier. Such carriers cross the barrier potential and contribute to current. This current is known as the forward current.

Q.57. Define reverse current in zero biased p-n junction diode. **[1 Mark]**

Ans: When the diode terminals are shorted together some holes generated in the n-side (minority carriers), move across the junction and contribute to current. This current is known as the reverse current.

***Q.58. What causes a larger current through a p-n junction diode when forward biased?** **[1 Mark]**

Ans: In case of forward bias the width of the depletion region decreases and the p-n junction offers a low resistance path allowing a high current to flow across the junction.

Q.59. Explain the I-V characteristics of a reverse biased junction diode. **[3 Marks]**

Ans:

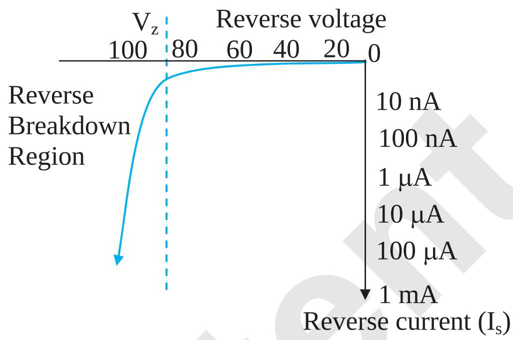
i. To reverse bias a diode, the positive terminal of the external voltage is connected to the cathode (n-side) and negative terminal to the anode (p-side) across the diode.

ii. In case of reverse bias the width of the depletion region increases and the p-n junction behaves like a high resistance.

iii. Practically no current flows through it with an increase in the reverse bias voltage. However, a very small leakage current does flow through the junction which is of the order of a few micro amperes, (μA).

iv. When the reverse bias voltage applied to a diode is increased to sufficiently large value, it causes the p-n junction to overheat. The overheating of the junction results in a sudden rise in the current through the junction. This is because covalent bonds break and a large number of carries are available for conduction. The diode thus no longer behaves like a diode. This effect is called the avalanche breakdown.

v. The reverse biased characteristic of a diode is shown in figure.



Reverse biased characteristic of a diode

Q.60. Explain zero biased junction diode. **[3 Marks]**

Ans:

i. When a diode is connected in a zero bias condition, no external potential energy is applied to the p-n junction.

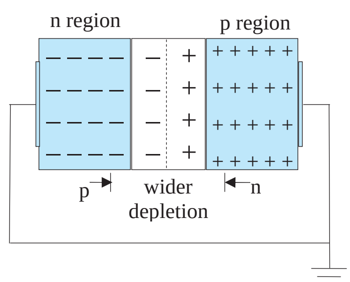
ii. The potential barrier that exists in a junction prevents the diffusion of any more majority carriers across it. However, some minority carriers (few free electrons in the p-region and few holes in the n-region) drift across the junction.

iii. An equilibrium is established when the majority carriers on both the sides of junction are equal in number ($n_e = n_h$) and are moving in opposite directions. The net current flowing across the junction is zero. This is a state of 'dynamic equilibrium'.

iv. The minority carriers are continuously generated due to thermal energy.

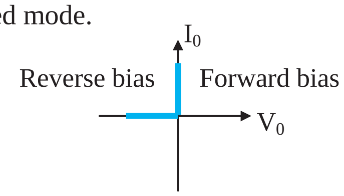
v. When the temperature of the p-n junction is raised, this state of equilibrium is changed.

vi. This results in generating more minority carriers and an increase in the leakage current. An electric current, however, cannot flow through the diode because it is not connected in any electric circuit.



Q.61. What is dynamic equilibrium? **[1 Mark]**
Ans: *Refer Q. 60 (iii)*

Q.62. Draw a neat diagram and state I-V characteristics of an ideal diode. **[2 Marks]**
Ans: An ideal diode offers zero resistance in forward biased mode and infinite resistance in reverse biased mode.

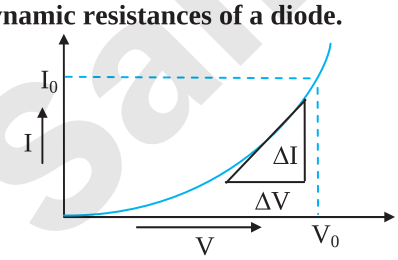


I-V Characteristics of an ideal diode

Q.63. What do you mean by static resistance of a diode? **[2 Marks]**
Ans: Static (DC) resistance:
i. When a p-n junction diode is forward biased, it offers a definite resistance in the circuit. This resistance is called the static or DC resistance (R_g) of a diode.
ii. The DC resistance of a diode is the ratio of the DC voltage across the diode to the DC current flowing through it at a particular voltage.
iii. It is given by, $R_g = \frac{V}{I}$

Q.64. Explain dynamic resistance of a diode. **[2 Marks]**
Ans:
i. The dynamic (AC) resistance of a diode, r_g, at a particular applied voltage, is defined as $r_g = \frac{\Delta V}{\Delta I}$
ii. The dynamic resistance of a diode depends on the operating voltage.
iii. It is the reciprocal of the slope of the characteristics at that point.

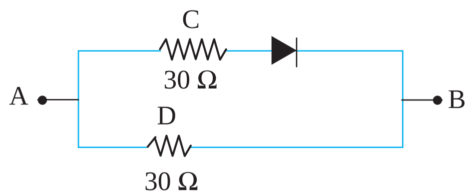
Q.65. Draw a graph representing static and dynamic resistances of a diode. **[1 Mark]**
Ans:



Static (DC) and dynamic (AC) resistance of a diode

Numerical Zone

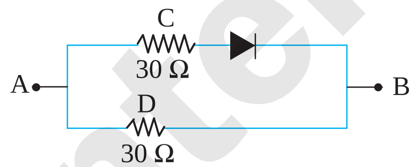
+**Q.66. Refer to the figure as shown below and find the resistance between point A and B when an ideal diode is (i) forward biased and (ii) reverse biased.**
(Example 14.3 of Textbook page no. 254) **[2 Marks]**



Solution:

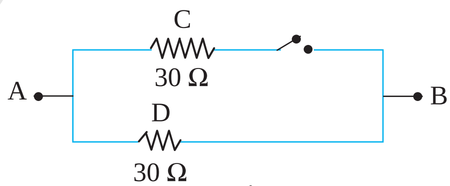
We know that for an ideal diode, the resistance is zero when forward biased and infinite when reverse biased.

i. Figure (a) shows the circuit when the diode is forward biased. An ideal diode behaves as a conductor and the circuit is similar to two resistances in parallel.



∴ $R_{AB} = \frac{30 \times 30}{30 + 30} = \frac{900}{60} = \mathbf{15\ \Omega}$

ii. Figure (b) shows the circuit when the diode is reverse biased.



Figure

It does not conduct and behaves as an open switch along path ACB. Therefore, R_{AB} = **30 Ω**, the only resistance in the circuit along the path ADB.

14.8 Semiconductor Devices

Q.67. State advantages of semiconductor devices. **[2 Marks]**
Ans:
i. Electronic properties of semiconductors can be controlled to suit our requirement.
ii. They are smaller in size and light weight.
iii. They can operate at smaller voltages (of the order of few mV) and require less current (of the order of μA or mA), therefore, consume lesser power.
iv. Almost no heating effects occur, therefore these devices are thermally stable.
v. Faster speed of operation due to smaller size.
vi. Fabrication of ICs is possible.

Q.68. State disadvantages of semiconductor devices. **[2 Marks]**

Ans:

i. They are sensitive to electrostatic charges.
ii. Not very useful for controlling high power.
iii. They are sensitive to radiation.
iv. They are sensitive to fluctuations in temperature.
v. They need controlled conditions for their manufacturing.
vi. Very few materials are semiconductors.

14.9 Applications of Semiconductors and p-n Junction Diode

Q.69. Explain applications of semiconductors. **[3 Marks]**

Ans:

i. Solar cell:
a. It converts light energy into electric energy.
b. It is useful to produce electricity in remote areas and also for providing electricity for satellites, space probes and space stations.

ii. Photo resistor: It changes its resistance when light is incident on it.

iii. Bi-polar junction transistor:
a. These are devices with two junctions and three terminals.
b. A transistor can be a p-n-p or n-p-n transistor.
c. Conduction takes place with holes and electrons.
d. Many other types of transistors are designed and fabricated to suit specific requirements.
e. They are used in almost all semiconductor devices.

iv. Photodiode: It conducts when illuminated with light.

v. LED (Light Emitting Diode):
a. It emits light when current passes through it.
b. House hold LED lamps use similar technology.
c. They consume less power, are smaller in size and have a longer life and are cost effective.

vi. Solid State Laser: It is a special type of LED. It emits light of specific frequency. It is smaller in size and consumes less power.

vii. Integrated Circuits (ICs): A small device having hundreds of diodes and transistors performs the work of a large number of electronic circuits.

Insights (1) - *Page no. 495*

The use of semiconductor devices in the field of electronics has substantially decreased the size of computers. Within a single semiconductor chip, many transistors, resistors and capacitors can be fabricated, packing much less space within a device.

GG - GYAN GURU

In 2018, plan of replacing old high pressure sodium vapour (HPSV) fittings of street lights by LED was set up as part of the Centre's Street Light National Programme (SLNP).
As per plan, LED lights were to set up in the streets of all major cities of Maharashtra including Mumbai, Navi Mumbai, Thane, Pune, Nashik etc.
As LED lights are energy efficient they would require only 28.47 million units of electricity as against 47.45 million units of electricity consumed by HPSV lights.

Q.70. Explain any four application of p-n junction diode. **[2 Marks]**

Ans: *Refer Q.69. (Solar cell, photodiode, LED and solid state laser only)*

14.10 Thermistor

Q.71. What is thermistor? **[1 Mark]**

Ans: *Thermistor is a temperature sensitive resistor. Its resistance changes with change in its temperature.*

Q.72. What are different types of thermistor and what are their applications? **[2 Marks]**

Ans: There are two types of thermistor:

i. **NTC (Negative Thermal Coefficient) thermistor:** Resistance of a NTC thermistor decreases with increase in its temperature. Its temperature coefficient is negative. They are commonly used as temperature sensors and also in temperature control circuits.

ii. **PTC (Positive Thermal Coefficient) thermistor:** Resistance of a PTC thermistor increases with increase in its temperature. They are commonly used in series with a circuit. They are generally used as a reusable fuse to limit current passing through a circuit to protect against over current conditions, as resettable fuses.

Q.73. How are thermistors fabricated? **[1 Mark]**

Ans: Thermistors are made from thermally sensitive metal oxide semiconductors. Thermistors are very sensitive to changes in temperature.

Q.74. Enlist any two features of thermistor. **[1 Mark]**

Ans:

i. A small change in surrounding temperature causes a large change in their resistance.

ii. They can measure temperature variations of a small area due to their small size.

Q.75. Write a note on:
i. Electric devices ii. Electronic devices **[2 Marks Each]**

Ans:

i. Electric devices:

a. These devices convert electrical energy into some other form.

b. **Examples:** Fan, refrigerator, geyser etc.
Fan converts electrical energy into mechanical energy. A geyser converts it into heat energy.

c. They use good conductors (mostly metals) for conduction of electricity.

d. Common working range of currents for electric circuits is milliampere (mA) to ampere.

e. Their energy consumption is also moderate to high. A typical geyser consumes about 2.0 to 2.50 kW of power.

f. They are moderate to large in size and are costly.

ii. Electronic devices:

a. Electronic circuits work with control or sequential changes in current through a cell.

b. A calculator, a cell phone, a smart watch or the remote control of a TV set are some of the electronic devices.

c. Semiconductors are used to fabricate such devices.

d. Common working range of currents for electronic circuits is nano-ampere to μA.

e. They consume very low energy. They are very compact, and cost effective.

Brain Teasers

Q.76. Can we take one slab of p-type semiconductor and physically join it to another n-type semiconductor to get p-n junction?

Ans:

i. No. Any slab, howsoever flat, will have roughness much larger than the inter-atomic crystal spacing (~2 to 3 Å).

ii. Hence, continuous contact at the atomic level will not be possible. The junction will behave as a discontinuity for the flowing charge carriers.

Q.77. What is Avalanche breakdown and zener breakdown?

Ans:

i. **Avalanche breakdown:** In high reverse bias, minority carriers acquire sufficient kinetic energy and collide with a valence electron. Due to collisions the covalent bond breaks. The valence electron enters conduction band. A breakdown occurring in such a manner is avalanche breakdown. It occurs with lightly doped p-n junctions.

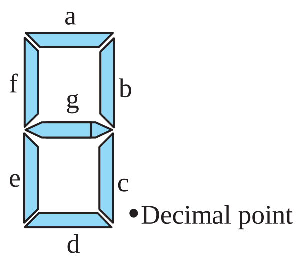
ii. **Zener breakdown:** It occurs in specially designed and highly doped p-n junctions, viz., zener diodes.
In this case, covalent bonds break directly due to application of high electric field.
Avalanche breakdown voltage is higher than zener voltage.

Q.78. Indicators on platform, digital clocks, calculators make use of seven LEDs to indicate a number. How do you think these LEDs might be arranged?

Ans:

i. The indicators on platforms, digital clocks, calculators are made using seven LEDs arranged in such a way that when provided proper signal they light up displaying desired alphabet or number.

ii. This arrangement of LEDs is called Seven Segment Display.



Q.79. Internet my friend *(Textbook page no. 256)*

i. https://www.electronics-tutorials.ws/diode

ii. https://www.hitachi-hightech.com

iii. https://nptel.ac.in/courses

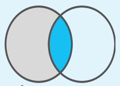
iv. https://physics.info/semiconductors

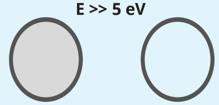
v. http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/semcn.html

[Students are expected to visit above mentioned links and collect more information regarding semiconductors.]

Memory Map

SOLIDS

Metals


Insulators
E >> 5 eV


Semiconductors

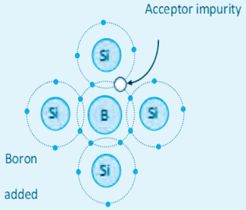
At T = 0 K
Valence band is completely filled and Conduction band is empty

At room temperature
Some of the valence electrons can be moved to the conduction band.

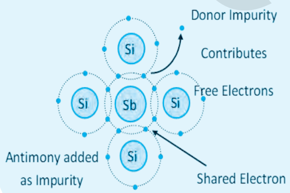
Elements of group IV, Valence = 4
Band gap has value less than 1 eV and it varies with the temperature

Intrinsic Semiconductors

Extrinsic Semiconductors

p- type


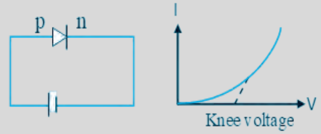
- $n_h >> n_e$
- $n_i^2 = n_e n_h$
- Dopant: Trivalent (Acceptor) eg.: B, Al, In, etc.
- Majority charge carriers: Holes

n- type


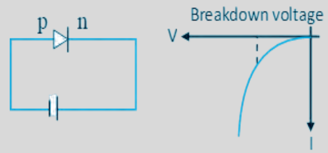
- $n_e >> n_h$
- $n_i^2 = n_e n_h$
- Dopant: Pentavalent (Donor) eg.: Sb, P, As, etc.
- Majority charge carriers: Electrons

p-n junction diode

Biasing of p-n junction

Forward biasing


- Width of depletion layer decreases.
- Switch ON state.

Reverse biasing


- Width of depletion layer increases.
- Switch OFF state.

p-n junction diode

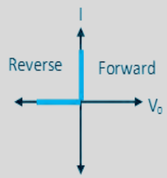
p-n junction


Without Biasing

Diffusion: Transfer of electrons and holes across p-n junction

Depletion Layer: Region across the junction devoid of charge carriers

Potential barrier: P.D. developed across the junction due to diffusion

Ideal Diode


Static Resistance:
$R_g = \frac{V}{I}$

Dynamic Resistance:
$r_g = \frac{\Delta V}{\Delta I}$

Important Formulae

1. **For a semiconductor**: $n_i^2 = n_e.n_h$

   where, n_i = Total number of intrinsic atoms,

   n_e = Total number of electrons,

   n_h = Total number of holes.

2. **Electrical conductivity of a solid:** $\sigma = nq\mu$

   where, n = charge carrier density,

   q = charge on the carriers,

   μ = mobility of carriers.

3. **Static (DC) Resistance:** $R_g = \frac{V}{I}$

4. **Dynamic (AC) Resistance:** $r_g = \frac{\Delta V}{\Delta I}$

Exercise

Theory Questions for Practice

14.2 Electrical Conduction in Solids

1. Enlist the factors affecting electrical conductivity of solids. **[1 Mark]**

Ans: *Refer Q.1*

2. Draw the graphs showing dependence of electrical conductivity of metals on the temperature. **[1 Mark]**

Ans: *Refer Q. 4 (Only Graph for metals)*

3. How does conductivity of semiconductors vary with temperature? **[1 Mark]**

Ans: *Refer Q.4 (ii)*

4. Classify the following semiconductors into elemental, compound and organic semiconductors: Silicon, polyaniline, zinc sulphide, germanium, Cadmium sulphide, **[1 Mark]**

Ans: *Refer Q.5*

5. State electrical properties of a semiconductor. **[2 Marks]**

Ans: *Refer Q.6*

14.3 Band Theory of Solids, a brief introduction

6. For a single sodium atom, describe the distribution of electron energy levels. **[3 Marks]**

Ans: *Refer Q. 7*

7. Describe formation of energy bands in solid sodium with energy band diagrams. **[4 Marks]**

Ans: *Refer Q.8*

8. Draw an energy band diagram showing potential energy curves for sodium metal. **[2 Marks]**

Ans: *Refer Q. 8 (Only Figure)*

9. What is valence band? **[1 Mark]**

Ans: *Refer Q.9 (i - a).*

10. Explain the concept of conduction band in solid crystal. **[2 Marks]**

Ans: *Refer Q.9 (ii)*

11. Describe band structures in conductors, insulators and semiconductors based on the band theory. **[3 Marks]**

Ans: *Refer Q.11*

12. State the conditions under which electrons in semiconductors start conducting electricity. **[2 Marks]**

Ans: *Refer Q.12*

13. What is 1 eV? **[1 Mark]**

Ans: *Refer Q.13*

14.4 Intrinsic Semiconductor

14. What do you mean by intrinsic semiconductor? **[1 Mark]**

Ans: *Refer Q.16*

15. Explain structure of silicon with the help of proper diagram. **[2 Marks]**

Ans: *Refer Q.17.*

16. How are holes formed in an intrinsic semiconductor? **[3 Marks]**

Ans: *Refer Q.18*

17. What are the factors affecting conductivity of a pure semiconductor at a given room temperature? **[2 Marks]**

Ans: *Refer Q.19*

18. Draw a neat labelled diagram showing conduction phenomenon in a pure semiconductor. **[2 Marks]**

Ans: *Refer Q. 20 (Only Diagram)*

19. What is the ratio of the number of holes and electrons in an intrinsic semiconductor? **[1 Mark]**

Ans: 1:1

14.5 Extrinsic Semiconductor

20. What is doping? **[1 Mark]**

Ans: *Refer Q.23 (i).*

21. Define extrinsic semiconductor. **[1 Mark]**

Ans: *Refer Q.24*

22. Explain formation of p-type semiconductor with proper diagram. **[3 Marks]**

Ans: *Refer Q.29*

23. What do you mean by donor impurity? **[1 Mark]**

Ans: *Refer Q.31.(i).*

24. What is acceptor impurity? [1 Mark]

Ans: *Refer Q.31.(ii).*

25. Draw diagrams showing the energy levels of both donor and acceptor impurities. [2 Marks]

Ans: *Refer Q.32*

26. Distinguish between n-type and p-type semiconductor. (Any two points) [2 Marks]

Ans: *Refer Q.33 (Any two points)*

27. Write a short note on the transportation of holes inside a p-type semiconductor. [2 Marks]

Ans: *Refer Q.35*

28. State the differences between intrinsic and extrinsic semiconductors. [2 Marks]

Ans: *Refer Q.37*

29. Which type of impurity can be added to pure silicon to make it a p-type semiconductor? [1 Mark]

Ans: Boron, Aluminium.

30. Which type of impurity can be added to pure silicon to make it n-type semiconductor? [1 Mark]

Ans: Phosphorous, Antimony

14.6 p-n junction

31. Define p-n junction. [1 Mark]

Ans: *Refer Q.41*

32. Explain diffusion across a p-n junction. [3 Marks]

Ans: *Refer Q.42.*

33. Define barrier potential. [1 Mark]

Ans: *Refer Q.43.*

34. Draw a neat labelled diagram for an electric field developed across a p-n junction. [2 Marks]

Ans: *Refer Q.45*

35. Define depletion layer. [1 Mark]

Ans: *Refer Q.46.(i).*

36. Why does a p-n junction need to be biased? [1 Mark]

Ans: *Refer Q.47*

37. Explain in detail the forward biasing of a p-n junction. [3 Marks]

Ans: *Refer Q.48*

38. Explain in detail the reverse biasing of a p-n junction. [3 Marks]

Ans: *Refer Q.49*

39. How does biasing affect the width of depletion layer in p-n junction? [2 Marks]

Ans: *Refer Q.50*

40. What is a depletion layer in a p-n junction diode? [1 Mark]

Ans: A depletion layer in a p-n junction diode is a thin layer of p and n section which is devoid of free electrons and holes.

41. Name the type of biasing which gives semiconductor diode, a very high resistance. [1 Mark]

Ans: Reverse biasing

42. What happens to the potential barrier when a p-n junction diode is forward biased? [1 Mark]

Ans: The potential barrier decreases in a forward biasing.

14.7 A p-n junction diode

43. Draw the V-I characteristics of p-n junction diode connected in forward bias. [2 Marks]

Ans: *Refer Q.54 (Only diagram)*

44. Define knee voltage. [1 Mark]

Ans: *Refer Q.55*

45. Define the terms forward current and reverse current in case of unbiased p-n junction diode. [1 Mark Each]

Ans: *Refer Q.56 and Q.57*

46. What is avalanche breakdown of diode? [1 Mark]

Ans: *Refer Q.59 (iv)*

47. Explain I-V characteristics of p-n junction diode as
i. Forward biased ii. Reverse biased [3 Marks Each]

Ans: *Refer Q.54 and Q.59*

48. What is zero biased p-n junction diode? Draw its diagram. [3 Marks]

Ans: *Refer Q.60*

49. What are static and dynamic resistances? [2 Marks]

Ans: *Refer Q. 63 and Q. 64(i)*

50. Draw a graph representing static and dynamic resistances of a diode. [1 Mark]

Ans: *Refer Q.65*

14.8 Semiconductor Devices

51. Give any four advantages of semiconductor devices. [2 Marks]

Ans: *Refer Q. 67 (Any four advantages)*

52. What are main disadvantages of semiconductor devices? [2 Marks]

Ans: *Refer Q.68*

14.9 Applications of Semiconductors and p-n junction diode

53. What are bipolar junction transistors? **[1 Mark]**

Ans: *Refer Q.69.(iii)*

54. Explain in brief any two applications of p-n junction diode. **[2 Marks]**

Ans: *Refer Q.69 (Any two amongst Solar cell, photodiode, LED and solid state laser)*

14.10 Thermistor

55. Define thermistor. **[1 Mark]**

Ans: *Refer Q.71*

56. What are the types of thermistors? **[1 Mark]**

Ans: *Refer Q.72 (Only types)*

57. What are the uses of thermistors? **[1 Mark]**

Ans: *Refer Q. 72 (Only applications)*

Additional Numericals for Practice

14.5 Extrinsic Semiconductor

1. A pure Si crystal has 2.5×10^{28} atoms m^{-3}. It is doped by 5 ppm concentration of antimony. Calculate the number of electrons and holes. Given $n_i = 1.5 \times 10^{16}/m^3$. **[2 Marks]**

Ans: 1.25×10^{23} m^{-3}, 1.8×10^{9} m^{-3}

2. The number of silicon atoms per m^3 is 5×10^{28}. This silicon is doped with 5×10^{22} atoms per m^3 of Arsenic and 5×10^{20} atoms per m^3 of Indium. Calculate the number of electrons and holes. (Given: $n_i = 1.5 \times 10^{16}$ m^{-3}) **[2 Marks]**

Ans: Number of electrons = 4.99×10^{22} $/m^3$
Number of holes = $4.5 \times 10^{9}/ m^3$

Multiple Choice Questions

[1 Mark Each]

1. The number of electrons in the valence shell of semiconductor is ________ .
(A) less than 4 (B) equal to 4
(C) more than 4 (D) zero

2. If the temperature of semiconductor is increased, the number of electrons in the valence band will ________.
(A) decrease
(B) remains same
(C) increase
(D) either increase or decrease

3. When N-type semiconductor is heated, the
(A) number of electrons and holes remains same.
(B) number of electrons increases while that of holes decreases.
(C) number of electrons decreases while that of holes increases.
(D) number of electrons and holes increases equally.

*4. Electric conduction through a semiconductor is due to:
(A) Electrons
(B) holes
(C) none of these
(D) both electrons and holes

5. In conduction band of solid, there is no electron at room temperature. The solid is ________ .
(A) semiconductors (B) insulator
(C) conductor (D) metal

6. In the crystal of pure Ge or Si, each covalent bond consists of ________ .
(A) 1 electron (B) 2 electrons
(C) 3 electrons (D) 4 electrons

7. A pure semiconductor is ________.
(A) an extrinsic semiconductor
(B) an intrinsic semiconductor
(C) p-type semiconductor
(D) n-type semiconductor

8. For an extrinsic semiconductor, the valency of the donor impurity is
(A) 2 (B) 1 (C) 4 (D) 5

9. In a semiconductor, acceptor impurity is ________ .
(A) antimony (B) indium
(C) phosphorous (D) arsenic

10. What are majority carriers in a semiconductor?
(A) Holes in n-type and electrons in p-type.
(B) Holes in n-type and p-type both.
(C) Electrons in n-type and p-type both.
(D) Holes in p-type and electrons in n-type.

11. When a hole is produced in P-type semiconductor, there is ________.
(A) extra electron in valence band.
(B) extra electron in conduction band.
(C) missing electron in valence band.
(D) missing electron in conduction band.

*12. The energy levels of holes are:
(A) in the valence band
(B) in the conduction band
(C) in the band gap but close to valence band
(D) in the band gap but close to conduction band

13. The number of bonds formed in p-type and n-type semiconductors are respectively
(A) 4, 5 (B) 3, 4
(C) 4, 3 (D) 5, 4

14. The movement of a hole is brought about by the valency being filled by a ________.
(A) free electrons (B) valence electrons
(C) positive ions (D) negative ions

15. The drift current in a p-n junction is
(A) from the p region to n region.
(B) from the n region to p region.
(C) from n to p region if the junction is forward biased and from p to n region if the junction is reverse biased.
(D) from p to n region if the junction is forward biased and from n to p region if the junction is reverse biased.

16. If a p-n junction diode is not connected to any circuit, then
(A) the potential is same everywhere.
(B) potential is not same and n-type side has lower potential than p-type side.
(C) there is an electric field at junction direction from p-type side to n-type side.
(D) there is an electric field at the junction directed from n-type side to p-type side.

17. In an unbiased p-n junction, holes diffuse from the p-region to n-region because
(A) free electrons in the n-region attract them.
(B) they move across the junction by the potential difference.
(C) hole concentration in p-region is more as compared to n-region.
(D) all the above.

*18. The potential barrier in p-n diode is due to:
(A) depletion of positive charges near the junction
(B) accumulation of positive charges near the junction
(C) depletion of negative charges near the junction,
(D) accumulation of positive and negative charges near the junction

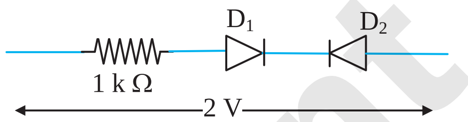
19. The width of depletion region ________.
(A) becomes small in forward bias of diode
(B) becomes large in forward bias of diode
(C) is not affected upon by the bias
(D) becomes small in reverse bias of diode

20. For p-n junction in reverse bias, which of the following is true?
(A) There is no current through P-N junction due to majority carriers from both regions.
(B) Width of potential barriers is small and it offers low resistance.
(C) Current is due to majority carriers.
(D) Both (B) and (C)

*21. Current through a reverse biased p-n junction, increases abruptly at:
(A) Breakdown voltage
(B) 0.0 V
(C) 0.3V
(D) 0.7V

*22. A reverse biased diode, is equivalent to:
(A) an off switch (B) an on switch
(C) a low resistance (D) none of the above

23. In the circuit shown below D_1 and D_2 are two silicon diodes. The current in the circuit is



(A) 2 A
(B) 2 mA
(C) 0.8 mA
(D) very small (approx 0)

24. For an ideal junction diode,
(A) forward bias resistance is infinity.
(B) forward bias resistance is zero.
(C) reverse bias resistance is infinity.
(D) both (B) and (C).

Answers to Multiple Choice Questions:

1.	(B)	2.	(A)	3.	(D)	4.	(D)
5.	(B)	6.	(B)	7.	(B)	8.	(D)
9.	(B)	10.	(D)	11.	(C)	12.	(C)
13.	(B)	14.	(B)	15.	(B)	16.	(D)
17.	(C)	18.	(D)	19.	(A)	20.	(A)
21.	(A)	22.	(A)	23.	(D)	24.	(D)

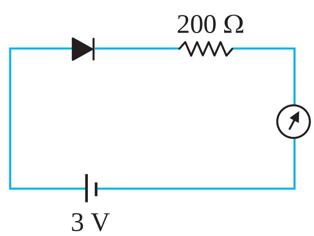
Solutions to Multiple Choice Questions:

17. In an unbiased p-n junction, the diffusion of charge carriers across the junction takes place from higher concentration to lower concentration.

Competitive Corner

1. In a p-n junction diode, change in temperature due to heating **[NEET (UG) 2018]**
(A) affects only reverse resistance.
(B) affects only forward resistance.
(C) does not affect resistance of p-n junction.
(D) affects the overall V-I characteristics of p-n junction.

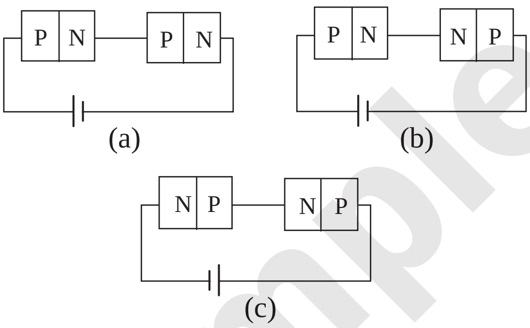
2. The reading of the ammeter for a silicon diode in the given circuit is: **[JEE (Main) 2018]**
(A) 11.5 mA
(B) 13.5 mA
(C) 0
(D) 15 mA



3. An intrinsic semiconductor is converted into n-type extrinsic semiconductor by doping it with **[NEET (UG) 2020]**
(A) germanium (B) phosphorous
(C) aluminium (D) silver

4. The electron concentration in an n-type semiconductor is the same as hole concentration in a p-type semiconductor. An external field (electric) is applied across each of them. Compare the currents in them. **[NEET (UG) 2021]**
(A) Current in p-type > current in n-type
(B) Current in n-type > current in p-type
(C) No current will flow in p-type, current will only flow in n-type.
(D) Current in n-type = current in p-type

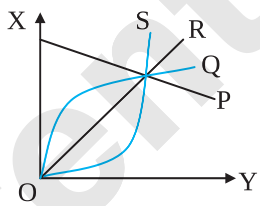
5. Which one is the wrong statement from the following? **[MHT CET 2021]**
(A) The resistance of an intrinsic semiconductor decreases with increase in temperature.
(B) A p-n junction diode is used in a rectifier.
(C) Electrons are the majority carriers in n-type semiconductor.
(D) To get p-type semiconductor, silicon should be doped with a pentavalent impurity.

6.


In the given circuits (a), (b) and (c), the potential drop across the two p-n junctions are equal in: **[NEET (UG) 2022]**
(A) Circuit (c) only
(B) Both circuits (a) and (c)
(C) Circuit (a) only
(D) Circuit (b) only

7. In a p-type semiconductor, **[MHT CET 2022]**
(A) electrons are minority carriers and pentavalent atoms are dopants.
(B) electrons are majority carries and pentavalent atoms are dopants.
(C) holes are majority carriers and trivalent atoms are dopants.
(D) holes are minority carriers and trivalent atoms are dopants.

8. Which one of the following graph represents forward bias characteristic of a diode? **[MHT CET 2022]**
(A) P
(B) Q
(C) R
(D) S



9. A p-type extrinsic semiconductor is obtained when Germanium is doped with: **[NEET (UG) Manipur 2023]**
(A) Arsenic (B) Boron
(C) Antimony (D) Phosphorous

10. When forward bias is applied to a p-n junction, then what happens to the potential barrier (V_B) and the width (X) of the depletion region? **[MHT CET 2023]**
(A) V_B increase, X decreases
(B) V_B decreases, X increase
(C) V_B increase, X increase
(D) V_B decreases, X decreases

11. For an intrinsic semiconductor (n_h and n_e are the number of holes per unit volume and number of electrons per unit volume respectively) **[MHT CET 2023]**
(A) $n_h < n_e$ (B) $n_h = n_e$
(C) $n_h = \frac{n_e}{2}$ (D) $n_h > n_e$

Answers to Competitive Corner:

1.	(D)	2.	(A)	3.	(B)	4.	(B)
5.	(D)	6.	(B)	7.	(C)	8.	(D)
9.	(B)	10.	(D)	11.	(B)		

Topic Test

Time: 1 Hour 30 Min **Total Marks: 25**

SECTION A

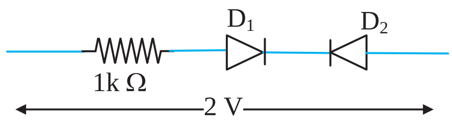
Q.1. Select and write the correct answer: **[04]**

i. The width of depletion region ________.
(A) becomes small in forward bias of diode (B) becomes large in forward bias of diode
(C) is not affected upon by the bias (D) becomes small in reverse bias of diode

ii. The number of bonds formed in p-type and n-type semiconductors are respectively
(A) 4, 5 (B) 3, 4 (C) 4, 3 (D) 5, 4

iii. For an extrinsic semiconductor, the valency of the donor impurity is
(A) 2 (B) 1 (C) 4 (D) 5

iv. In the circuit shown below D_1 and D_2 are two silicon diodes. The current in the circuit is
(A) 2 A
(B) 2 mA
(C) 0.8 mA
(D) very small (approx 0)



Q.2. Answer the following: **[03]**

i. What is knee voltage?

ii. Which element would you use as an impurity to make germanium an n-type semiconductor?

iii. Define 1 eV.

SECTION B

Attempt any Four: **[08]**

Q.3. What are donor and acceptor impurities?

Q.4. Distinguish between p-type and n-type semiconductor.

Q.5. A semiconductor has equal electron and hole concentration of 2×10^8 m^{-3}. On doping with a certain impurity, the electron concentration increases to 4×10^{10} m^{-3}, then calculate the new hole concentration of the semiconductor.

Q.6. What is p-n junction diode? Draw its circuit symbol.

Q.7. What do you mean by static resistance of a diode?

Q.8. What are different types of thermistor and what are their applications?

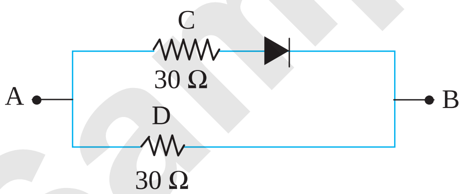
SECTION C

Attempt any Two: **[06]**

Q.9. Explain the I-V characteristic of a forward biased junction diode.

Q.10. Explain the process of diffusion in p-n junction.

Q.11. Refer to the figure as shown below and find the resistance between point A and B when an ideal diode is (i) forward biased and (ii) reverse biased.



SECTION D

Attempt any One: **[04]**

Q.12. With the help of neat diagram, explain the structure of p-type semiconductor in detail.

Q.13 With the help of neat diagram, explain the structure of n-type semiconductor in detail.

Scan the given Q. R. Code in *Quill - The Padhai App* to view Solutions of:
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ii. Additional Numericals for Practice
iii. Competitive Corner
iv. Topic Test